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IS 14956 (2001): Live Working - Minimum Approach Distances
- Method of Calculation [ETD 36: Tools and Equipment for
Live Working]



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“Knowledge is such a treasure which cannot be stolen”

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भारतीय मानक

चालू बिजली की लाईन पर कार्य करना —
न्यूनतम निकटता दूरी परिकल्प पद्धति

Indian Standard

LIVE WORKING — MINIMUM APPROACH
DISTANCES — METHOD OF CALCULATION

ICS 13.260; 29.240.20; 29.260.99

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NATIONAL FOREWORD

This Indian Standard which is identical with IEC 61472 (1998) 'Live working — Minimum approach distances — Method of calculation' issued by the International Electrotechnical Commission (IEC) was adopted by the Bureau of Indian Standards on the recommendation of the Tools and Equipment for Live Working Sectional Committee and approval of the Electrotechnical Division Council.

This standard specifies a method of calculating the minimum approach distance for live working, at voltages between 1 kV and 800 kV, required to protect workers from system overvoltages. This standard addresses system overvoltages, and the working air distances between parts and/or workers at different potentials.

The text of the IEC standard has been approved as suitable for publication as Indian Standard without deviations.

In the adopted standard, certain terminology and conventions are not identical to those used in Indian Standards. Attention is specially drawn to the following:

- a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'.
- b) Comma (,) has been used as a decimal marker while in Indian Standards, the current practice is to use a point (.) as the decimal marker.

Only the English text of the International Standard has been retained while adopting it in this Indian Standard.

CROSS REFERENCES

In this adopted standard, reference appears to the following International Standard for which Indian Standard also exists. The corresponding Indian Standard, which is to be substituted in its place, is listed below along with its degree of equivalence for the edition indicated.

<i>International Standard</i>	<i>Corresponding Indian Standard</i>	<i>Degree of Equivalence</i>
IEC 60050 (604) : 1987 International Electro-technical Vocabulary — Chapter 604 :Generation, transmission and distribution of electricity — Operation	1885 (Part 70) : 1993 Electrotechnical vocabulary; Part 70 Generation, transmission and distribution of electricity — Operation	Identical

The technical committee responsible for the preparation of this standard has reviewed the provisions of the following International Standard referred in this adopted standard and has decided that it is acceptable for use in conjunction with this standard:

IEC 60050 (601) : 1985 International electrotechnical vocabulary — Chapter 601:Generation, transmission and distribution of electricity — General

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding of numerical values (revised)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

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Indian Standard

LIVE WORKING — MINIMUM APPROACH DISTANCES — METHOD OF CALCULATION

1 Scope

This International Standard specifies a method for calculating the minimum approach distance for live working, at voltages between 1 kV and 800 kV, required to protect workers from system overvoltages. This standard addresses system overvoltages, and the working air distances between parts and/or workers at different potentials.

The calculation of distances for d.c. voltages is presently under consideration.

The required withstand voltage and minimum approach distances calculated by the method described in this standard are recommended for use only if the following working conditions prevail:

- workers are trained for, and skilled in, working live lines or close to live conductors;
- the operating conditions are adjusted so that the statistical overvoltage does not exceed the value selected for the determination of the required withstand voltage;
- transient overvoltages are the determining overvoltages;
- tool insulation has no continuous film of moisture present on the surface;
- no lightning is observed within 10 km of the work site;
- allowance is made for the effect of conducting components of tools;
- the effect of altitude on the electrical strength is taken into consideration.

NOTE – In some countries, special procedures have been developed to permit live working with surface moisture on tools at distribution voltages (below 50 kV).

2 Normative references

The following normative documents contain provisions which, though referenced in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60050(601):1985, *International Electrotechnical Vocabulary (IEV) – Chapter 601: Generation, transmission and distribution of electricity – General*

IEC 60050(604):1987, *International Electrotechnical Vocabulary (IEV) – Chapter 604: Generation, transmission and distribution of electricity – Operation*

3 Definitions

For the purpose of this International Standard, the following definitions apply.

3.1

highest voltage of a system (U_s)

the highest value of operating voltage which occurs under normal operating conditions at any time and any point in the system (phase-to-phase voltage)

NOTE – Transient overvoltages due for example to switching operations and abnormal operation and abnormal temporary variations of voltage, are not taken into account. [IEV 601-01-23 modified]

3.2

transient overvoltage

a short duration overvoltage of a few milliseconds or less, oscillatory or non-oscillatory, usually highly damped. [IEV 604-03-13]

3.3

fifty per cent disruptive discharge voltage (U_{50})

the peak value of an impulse test voltage having a 50 % probability of initiating a disruptive discharge each time the dielectric testing is performed. [IEV 604-03-43]

3.4

statistical withstand voltage (U_{90})

the overvoltage at which the insulation exhibits a 90 % probability of withstand

3.5

statistical overvoltage (U_2)

the overvoltage that has a 2 % probability of being exceeded

3.6

per unit value (u)

the expression of the per unit value of the amplitude of an overvoltage (or of a voltage) referred to $U_s \sqrt{2} / \sqrt{3}$

NOTE – This applies to u_{e2} , u_{p2} , u_{e1} and u_{p1} defined below.

3.7

minimum approach distance (D_A)

the minimum distance in air to be maintained between any part of the body of a worker, or any conductive tool being directly handled, and any part at different potentials. This minimum working distance will vary depending upon the chosen electrical and ergonomic components.

3.8

electrical distance (D_U)

the distance in air which protects against electrical breakdown during live working. In generic terms, the electrical component of the minimum working distance between two electrodes which represent live and/or earthed parts, required to prevent sparkover under the most severe electrical stress that will arise under the chosen conditions.

3.9

ergonomic distance (D_E)

the distance which allows for inadvertent movement or errors in appraising distances while performing work. This distance takes into consideration the actions of the persons as well as the tools that are to be used and manipulated.

4 Methodology

The methodology of the calculation of the minimum approach distances is based on three considerations:

- to establish the statistical overvoltage expected in the work area (U_2) and from this determine the required statistical withstand voltage of the insulation in the work area (U_{90});
- to calculate the minimum electrical distance D_U related to U_{90} ;
- to add an additional distance to allow for ergonomic factors associated with live working, such as inadvertent movement.

The minimum approach distance D_A is thus determined by:

$$D_A = D_U + D_E \quad (1)$$

where

D_U is the minimum electrical distance necessary to obtain U_{90} ;

D_E is the ergonomic distance which allows for the control of the minimum approach distance developed through work procedures, level of training, skill of the workers, type of construction, and such contingencies as inadvertent movement, and errors in appraising distances. The value chosen for the ergonomic distance D_E differs between users. Three variations of D_E with system voltage have been used: increasing, decreasing and constant. The value of D_E will be specific to each user but it generally falls within the range of 0,2 m to 1 m (see annex G for details).

The illustration of the components of the minimum approach distance D_A is shown in figure 1.

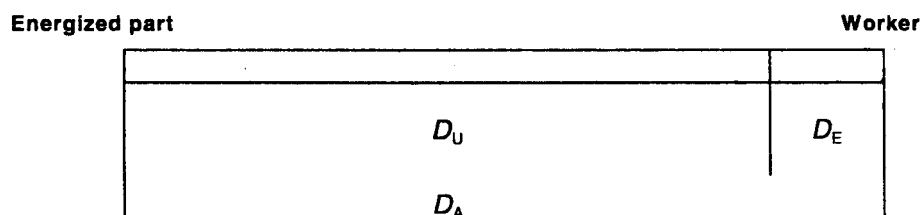


Figure 1 – Illustration of components of D_A

5 Factors influencing calculations

5.1 Control of system overvoltages

The maximum amplitude of overvoltages arriving in the work area can be reduced by the usual practice of making the circuit-breaker reclosing devices inoperative, or by using protective gaps or surge arresters. Protective gaps are used on transmission systems at voltages above 69 kV. They are preferably installed close to the work area, or at equipment terminations.

5.2 Statistical overvoltage

The electrical stress at the work area shall be known. The electrical stress is described as the statistical overvoltage that may be present at the work area. In a 3-phase a.c. power system the statistical overvoltage U_{e2} between phase and earth is:

$$U_{e2} = \sqrt{2} / \sqrt{3} U_s u_{e2} \quad (2)$$

where

U_s is the highest voltage of the system;

u_{e2} is the statistical overvoltage phase-to-earth expressed in per unit.

Similarly:

$$U_{p2} = \sqrt{2} / \sqrt{3} U_s u_{p2} \quad (3)$$

where

u_{p2} is the statistical overvoltage phase-to-phase expressed in per unit.

If the per unit phase-phase data are not available, an approximate value can be derived from u_{e2} by the following formula:

$$u_{p2} = 1,33 u_{e2} + 0,4 \quad (4)$$

The transient overvoltages to be considered are those caused by system faults and switching operations, whether they occur on the lines being worked, or on adjacent lines or associated equipment.

The values of statistical overvoltages shall be those measured or determined by transient network analyzer (TNA) or digital computer studies. If such studies do not provide the statistical overvoltages (2 % values) but only the "truncated values", without the statistical distribution, the transformation of the truncated values into 2 % values can be made (see annex A). Typical values of statistical overvoltages are shown in annex A, for use when no other values are available.

5.3 Gap strength

For the determination of the minimum approach distance, the required withstand voltage for live working is taken to be equal to the voltage U_{90} , determined from the general expression

$$U_{90} = K_s U_2 \quad (5)$$

Considering the phase-to-earth and phase-to-phase voltages separately and combining equation (5) with equations (2) and (3) gives:

$$U_{e90} = K_s \sqrt{2} / \sqrt{3} U_s u_{e2} \quad (6)$$

$$U_{p90} = K_s \sqrt{2} / \sqrt{3} U_s u_{p2} \quad (7)$$

where

U_{90} is a statistical withstand voltage (the overvoltage at which the insulation exhibits a 90 % probability of withstand);

U_2 is the 2 % statistical overvoltage;

K_s is the statistical factor;

U_{e90} and U_{p90} are the statistical withstand voltages phase-to-earth and phase-to-phase, respectively,

u_{e2} and u_{p2} are the corresponding statistical overvoltages, expressed in per unit.

5.4 Calculation of electrical distances

The strength of the gap is influenced by a series of considerations which can be combined in a factor K_t used in the following formula for calculating D_U :

$$D_U = 2,17 (e^{U_{90}/(1080K_t)} - 1) + F \quad (8)$$

where F is the floating object distance (see subclause 5.4.4).

K_t is given by:

$$K_t = k_s k_g k_a k_f k_i \quad (9)$$

5.4.1 Conventional deviation factor k_s

Factor k_s accounts for the statistical nature of the breakdown voltage. Unless the value of the normalized conventional deviation, s_e , is known from tests representing the gap configuration and distance used, a value of 0,936, based on a normalized conventional deviation of 5 %, for positive impulses, can be used (see annex B).

5.4.2 Gap factor k_g

The gap factor k_g takes into account the effect of the gap configuration on the dielectric strength of air (see annex C).

NOTE 1 – Unless an appropriate gap factor can be selected for the structure configurations that exist at the system voltage being considered, a generally conservative value of $k_g = 1,2$ is recommended, to allow for a variety of configurations.

NOTE 2 – CIGRÉ Brochure 72 [1]* and IEC 60071-2 [2] provide more information concerning the determination of k_g for various gap configurations.

5.4.3 Atmospheric factor k_a

The electric strength of the air insulation in the work area is affected by the altitude above sea level. This effect, which varies to some extent with the gap length, or conversely with the withstand voltage, is accounted for by the atmospheric factor k_a . The appropriate value of k_a can be selected from table D.1 or calculated for a specific altitude and U_{90} by the method given in annex D, for a reference altitude below which most live work is done.

* Figures in square brackets refer to the bibliography given in annex H.

The electrical distance D_U should be increased when live work is carried out in locations higher than the reference altitude in order to account for the lower mean atmospheric pressure. This can be done by multiplying D_U by an altitude correction factor, which can be calculated using the equations given in annex D. If a reference altitude of 1 000 m is chosen, the applicable values of the altitude correction factor can be taken from table D.2.

5.4.4 Floating object factor k_f

Floating objects can decrease, or increase, the electric strength of a gap by field distortion.

A conductive object placed between two electrodes at different potentials, and not connected to either one, is electrically floating, and acquires an intermediate potential. The extent of the influence these conductive floating objects have on the electric strength of the gap varies depending on the number of floating objects, their dimensions, shapes and geometrical positions in the gap. Nevertheless, the presence of the floating object(s) reduces the net electrical length of the air gap.

When calculating the effects of floating objects, all possible disruptive discharge paths should be considered in determining the factors k_f and F .

The effects of floating objects on the strength of a gap are accounted for by the floating object factor k_f and a floating object distance F (sum of all dimensions, in the direction of the gap axis, of the floating objects in the air gap), based on the following configuration:

- a) when no floating object is present, $k_f = 1$ and $F = 0$;
- b) the floating object factor $k_f = 0,85$ shall be applied in the following three cases:
 - $U_s < 72,5$ kV, $L > 150$ mm, floating object stationary;
 - $U_s < 72,5$ kV, $L > 300$ mm, floating object moving;
 - $U_s > 72,5$ kV, $L > 300$ mm, floating object moving or stationary;

where L is the greatest value of any floating object length, taken in the direction along the gap axis;

- c) in all other cases the factor, $k_f = 1$ shall be applied.

The influence of metallic caps and pins of suspension insulators is negligible and shall be ignored.

See annex F for more details.

5.4.5 Insulators

When there is no damaged insulator present, $k_i = 1,0$. At all times, care shall be taken that the electrical integrity of the insulator assembly is not impaired by tools in parallel, moisture or contamination on the surface and damaged insulators (see annex E).

The effect of damaged insulation on the withstand voltage in the work area shall be allowed for by ensuring that a minimum amount of undamaged system insulation is always present while working live near the insulation. The minimum system insulation length shall be determined from equation (8) using a value of k_i given in the empirically-derived and conservative formula (10), unless the minimum system insulation requirement is known from test data or by other means. The calculated value of D_U is the minimum insulation length measured between live and earth electrodes. In this case it is not the minimum approach distance.

$$k_i = 1 - 0,8 k_d n_d / n_o \quad (10)$$

where

n_d is the number of damaged units in a string of n_o units;

k_d is a coefficient characterizing the average state of the damaged units;

$k_d = 1$ for toughened glass insulators;

$k_d = 0$ to 1 for porcelain insulators, with $k_d = 0,75$ as an average value.

Consideration of arcing horn or grading ring spacing shall also be taken into account (see annex E).

The effect of arcing horns or grading rings is to shield to some extent the insulator units between them. Consideration should be given to this when determining k_i . This can be done by using equation (10), with n_o the number of units in an insulator string that are not shunted by arcing horns or grading rings, and n_d the number of damaged units included in n_o .

NOTE 1 – Units shielded by horns or rings do not significantly contribute to the dielectric strength of the string, hence damage in this area is less important and the units can be shorted during work.

The situation with multiple string assemblies and vee-strings is more complex than for a single string.

NOTE 2 – It appears that, at least for duplex strings, the most severe reduction of the dielectric strength occurs when damaged insulators are partly in one string, partly in the other, and not in adjacent positions in each string.

For non-ceramic insulators, there is no established method for determining their electrical strength while in service. The risk of flashover during live work can therefore not be determined.

5.4.6 Examples of work configuration relative to values of k_i and k_g

When the system insulation comprises only single insulators which are suspected to be damaged, it is clear that they will sustain the power frequency voltage, but it is not possible to determine whether or not they will sustain overvoltages without a flashover. The decision as to whether it is safe to work on these insulators has to be left to the experience of the companies undertaking the work.

Figure 2 illustrates various distinct live working tasks and the configurations in which they can occur.

Table 1 provides ranges of values of k_i and k_g for the configurations illustrated in figure 2.

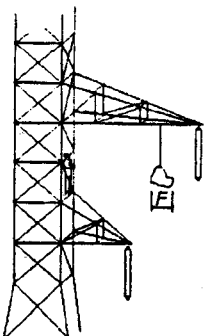
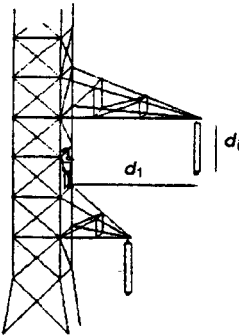
Table 1 – Distances for tasks of figure 2 (phase-to-earth)

Figure 2	Base case $k_i^{1)}$	Floating object $k_i^{2)}$	$k_g^{3)}$	Minimum distance
a)	1,0	0,85	1,1 to 1,6	$d_1 > D_A$
b)	1,0	0,85	1,1 to 1,6	$d_1 > D_A$
c)	0,85	0,85	1,1 to 1,45	$D_A < \text{the smallest distance between } d_1 + d_3 \text{ or } d_2 + d_3$
d)	1,0	0,85	1,0 to 1,45	$D_A < \text{the smallest distance between } d_1 \text{ or } d_2, \text{ and } d_3 \text{ or } d_4$
NOTE 1 – In each case, any damaged insulators should be taken into account by k_i .				
NOTE 2 – With floating objects in the air gap, add the maximum dimension F of the object to obtain D_U .				
1) Refers to the left column of sketches in figure 2.				
2) Refers to the right column of sketches in figure 2.				
3) Overall range of values; see annex C to calculate k_g .				

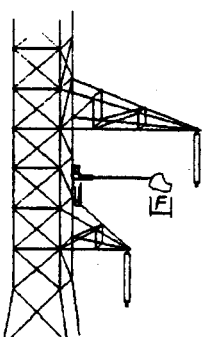
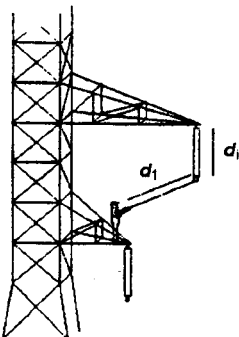
Without floating object

With floating object

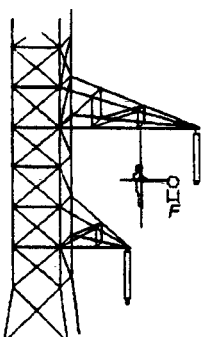
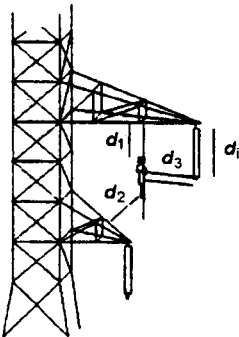
a) Worker not in air gap



b) Worker using hot stick



c) Worker at intermediate potential



d) Barehand work

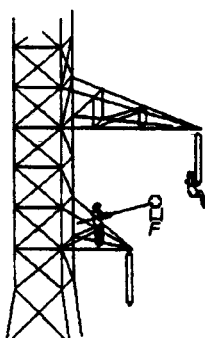
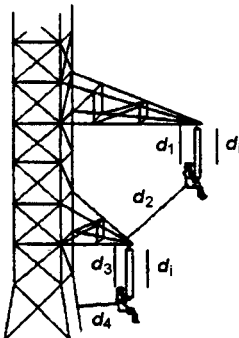


Figure 2 – Typical live working tasks

6 Evaluation of risks

The overall risk of breakdown of the insulation at the work area is associated with a number of situations described below. These situations when combined reduce the overall risk of breakdown. They are as follows:

- the actual system voltage is not always at a maximum value;
- the location of the work is not likely to correspond to the place where a transient overvoltage is at the maximum value;
- the stress of the actual transient overvoltage wavefront is less than the critical front;
- approximately half of the transient overvoltages will be of negative polarity, and are less severe;
- the frequency and amplitude of transient overvoltages are reduced by restricting reclosure of circuit-breakers.

Thus, the value of 1,1 is recommended for K_s to reduce the overall risk of breakdown of the insulation to a level that correlates with other electrical work operations.

The overall risk of a breakdown occurring during live working when an ergonomic distance D_E is incorporated will be lower because an overvoltage is unlikely to arise at the work area at that instant where the ergonomic distance is entirely breached by inadvertent movement of the worker or object. Because of this, a value of $K_s = 1,0$ can be used when a defined ergonomic distance D_E is included and is great enough that the value of D_A is always greater than the value of D_U calculated using $K_s = 1,1$ i.e.:

$$D_{U(K_s = 1,0)} + D_E > D_{U(K_s = 1,1)}$$

where $D_{U(K_s = 1,0)}$ and $D_{U(K_s = 1,1)}$ are D_U calculated using $K_s = 1,0$ and $K_s = 1,1$ respectively. But, in doing so, the effective ergonomic distance, D_E , is reduced and shall then be more tightly controlled to retain the same overall risk of breakdown.

7 Calculation of minimum approach distance

The electrical distance D_U is calculated (in metres) from:

$$D_U = 2,17 (e^{U_{90}/(1080K_t)} - 1) + F \quad (8)$$

where

F is the floating object length (see 5.4.4);

$U_{90} = K_s U_2$ (from equation (5));

K_t is obtained in equation (9) $K_t = k_s k_g k_a k_f k_i$.

After selecting an appropriate value for the ergonomic distance D_E (see annex G), the minimum approach distance D_A can then be determined by equation (1):

$$D_A = D_U + D_E \quad (1)$$

NOTE – The value chosen for the ergonomic distance differs between users. It generally falls in the range of 0,2 m to 1 m (see annex G).

An example of the calculation results is shown in figure 3 for values of the various factors. The electrical distance D_U is plotted against highest system voltage U_s for various levels of 2 % switching overvoltage u_{e2} , and for $K_t = 1,1$; $k_s = 0,936$; $k_g = 1,2$; k_a taken from table D.1 for 1 000 m altitude; k_f and $k_i = 1,0$ and $F = 0$.

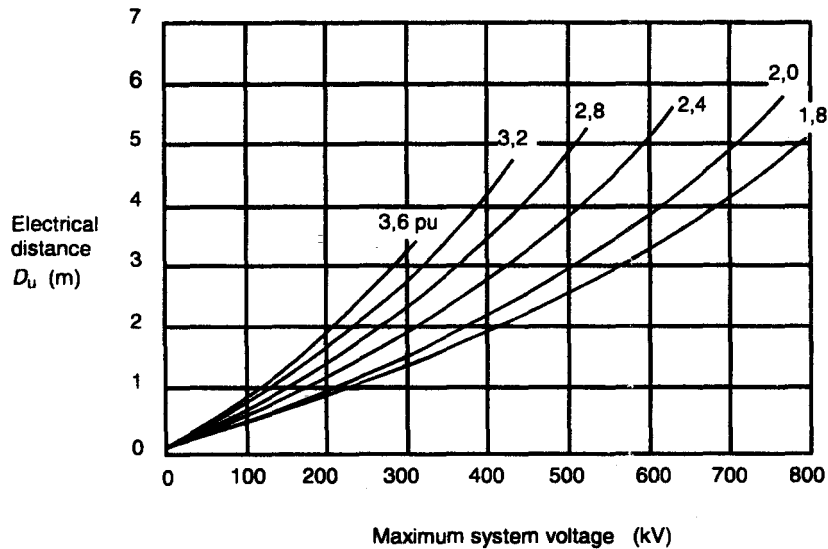


Figure 3 – Calculation of minimum approach distance

Annex A **(informative)**

Overvoltages

In establishing the minimum approach distance five distinct types of electrical stresses shall be considered. Each type of stress has its own influence; all may not be present at any one time. They are as follows:

- nominal system voltage (see IEC 60038 [3]);
- highest voltage of a system U_s [IEV 601-01-23];
- temporary overvoltage [IEV 604-03-12];
- transient overvoltage [IEV 604-03-13]:
 - switching;
 - lightning;
- induced voltage:
 - power frequency electrical (capacitive);
 - power frequency magnetic (inductive);
 - transient.

A discussion follows of the essential points associated with each electrical stress as related to minimum approach distance.

A.1 Nominal system voltage

Nominal system voltages are presented in IEC 60038. These voltages are associated with standard ranges. Actual system voltage may not follow these guidelines.

A.2 Highest voltage of a system

In reality, the calculation of the overvoltage is based on the highest voltage of a system U_s which is specific to the operating system and may or may not be known. Unless its actual value is known U_s may be derived from the nominal voltage of the system by using the corresponding value of the highest voltage for equipment U_m , given in IEC 60038, i.e. the highest r.m.s. value of phase-to-phase voltage for which the equipment is designed.

A.3 Temporary overvoltage

A temporary overvoltage can be generated by system faults, resonance, sudden load rejection and some other operating conditions. Its most common and significant use in establishing minimum approach distance is for earth fault-generated overvoltage, which arises on the unfaulted phases and can reach 1,7 per unit (pu) at the fault point on some systems.

A.4 Transient overvoltage

A transient overvoltage has a shape which can be regarded for minimum approach distance as that associated with a number of factors, including:

- energization;
- fault initiation;
- fault clearing;
- de-energizing and reclosing of a portion of the transmission system or its equipment (e.g. transformers or capacitor banks).

In systems with high earth fault factors (e.g. in resonant earthed or unearthed neutral systems), transient overvoltages due to earth faults shall also be considered.

Transient overvoltages that can appear at the work site vary considerably in shape and magnitude, but they are generally highly damped and of short duration.

A.4.1 Switching overvoltage

The maximum switching overvoltages that can reach the work site are usually due to switching of the line or equipment on which work is being performed. When feasible, the reclosing devices are made inoperative during live working, so that the line is not re-energized should it trip while work is in progress. This serves two purposes. Firstly, should there be an accidental flashover in the work area, it allows time for workers to safeguard the work area before re-energization of the installation. Secondly, it limits the source of maximum overvoltages to de-energizing transients, except in the exceptionally rare instance of a circuit-breaker restriking.

The magnitude of the switching overvoltage depends on the performance of the circuit-breaker and the electrical characteristics of the line. Therefore, it varies from one system to another. With circuit-breakers using closing, reclosing and opening resistors, or when metal oxide surge arresters are installed and operating properly, the magnitude is highly reduced.

The value of switching overvoltages for each voltage level of a power system can be determined by a transient network analyser (TNA) or a digital computer study. Such a study should provide a value for the 2 % statistical overvoltage U_2 from which the minimum approach distance can then be determined. However, if only the overall maximum pu overvoltage is known, this value is taken to be the truncated value, that is the value beyond which no overvoltages occur and which is taken (IEC 60071-2) to be three deviations above the mean.

The following empirical relationships given in IEC 60071-2 can then be used to estimate the 2 % statistical overvoltage U_2 from the truncated values (using the "phase-peak" method in each case).

For phase-to-earth overvoltages:

For the 2 % statistical overvoltage u_{e2} in per unit (pu):

standard deviation	$\sigma_e = 0,25 (u_{e2} - 1)$
truncated value	$u_{et} = 1,25 u_{e2} - 0,25$

hence:

$$u_{e2} = (u_{et} + 0,25) / 1,25$$

For phase-to-phase overvoltages:

For the 2 % statistical overvoltage phase-to-phase u_{p2} :

standard deviation	$\sigma_p = 0,25 (u_{p2} - 1,73)$
truncated value	$u_{pt} = 1,25 u_{p2} - 0,43$

hence:

$$u_{p2} = (u_{pt} + 0,43) / 1,25$$

If no phase-to-phase overvoltage data is available a value for u_{p2} can be estimated using the diagram given in IEC 60071-2.

For system voltages above 72,5 kV, if the value of the maximum per unit switching overvoltage is not known from system tests or studies, the statistical (2 %) overvoltage values shown in tables A.3 and A.4 should be used.

A.4.2 Lightning overvoltages

Work on or near live or dead lines or equipment should not be done when lightning is perceived in the immediate vicinity (e.g. 5 km to 10 km). A remote storm, not noticeable to the workers, may cause an overvoltage on the live installations. Such an overvoltage is attenuated as it travels toward the work area. It may also double at the remote open end of a line. For safe working, the overvoltage shall be less than the value of the withstand strength at the work area U_{90} . This is the case when the work area is more than 10 km away from the source of the lightning strike, even with an open-ended line. Since lightning can usually be visually or audibly detected at this distance, live work should not be conducted if lightning can be seen or thunder heard.

NOTE – If lightning causes a fault anywhere on a system, there will be a fault-generated overvoltage, an opening overvoltage and, if reclosing is not inoperative, a more severe closing overvoltage will also result. These events stress all the insulation at the work area.

If protective gaps are used at the work area the U_{90} value will be greatly limited by the gaps and a gap flashover can occur even if the lightning strike is much further away than 10 km.

While the gap thus provides added protection against lightning flashover in the work area, it can also cause undesirable sustained outages, due to the auto reclosing device being inoperative.

A.5 Induced voltage

An installation that is disconnected from its normal source of supply (either earthed or unearthed) may be subjected to induction from other energized installations. When work is performed on such an installation, a minimum approach distance sufficient for the induced voltage level should be maintained. For these installations, the maximum voltage induced by capacitive coupling is generally less than 30 % of the phase-to-earth voltage of the adjacent energized installation. If the induced voltage on the installation being worked on is not known, the 30 % value should be used.

For installations with a significant induced coupling situation such as an aerial to underground line, the actual voltage at the work area shall be established before the energized part is approached. Consideration should be given to the possibility of a fault occurring on the live installation, in which case the transient coupled induced voltage will also be significant.

**Table A.1 – System voltages up to 72,5 kV –
Typical switching impulse withstand voltages phase-to-earth**

Highest system voltage U_s kV (r.m.s.)	2 % switching overvoltage u_{e2} pu			90 % switching impulse withstand voltage U_{90} kV ¹⁾			Electrical distance for common u_{e2} D_U cm ²⁾
	Low	Common	High	Low	Common	High	
1,0	2,2	2,7	3,5	2	2,4	3,1	5
7,2	2,2	2,7	3,5	14	17	23	5
17,5	2,2	2,7	3,5	35	42	55	7
24,0	2,2	2,7	3,5	47	58	75	11
26,4	2,2	2,7	3,5	52	64	83	12
36,0	2,2	2,7	3,5	71	87	113	19
40,5	2,2	2,7	3,5	80	98	127	21
52,0	2,2	2,7	3,5	103	126	163	29
72,5	2,2	2,7	3,5	143	176	228	42

1) Calculated using formula $U_{90} = 1,1 \sqrt{2} / \sqrt{3} U_s u_{e2}$.

2) Using equation (2) with 5 cm minimum and $k_a = 0,901$ (1 000 m reference altitude).

**Table A.2 – System voltages up to 72,5 kV –
Typical switching impulse withstand voltages phase-to-phase**

Highest system voltage U_s kV (r.m.s.)	2 % switching overvoltage u_{p2} pu ¹⁾			90 % switching impulse withstand voltage U_{90} kV ³⁾			Electrical distance for common u_{p2} D_U cm ²⁾
	Low	Common	High	Low	Common	High	
1,0	3,3	4,0	5,1	3	3,6	4,6	5
7,2	3,3	4,0	5,1	21	26	33	5
17,5	3,3	4,0	5,1	52	63	80	12
24,0	3,3	4,0	5,1	71	86	110	18
26,4	3,3	4,0	5,1	78	95	121	21
36,0	3,3	4,0	5,1	107	129	165	30
40,5	3,3	4,0	5,1	120	146	186	34
52,0	2,2	2,7	3,5	154	187	238	45
72,5	2,2	2,7	3,5	215	260	332	64

1) Calculated using formula $u_{p2} = 1,33 u_{e2} + 0,4$.
2) Using equation (2) with 5 cm minimum and $k_a = 0,901$ (1 000 m reference altitude).
3) Calculated using formula $U_{90} = 1,1 \sqrt{2} / \sqrt{3} U_s u_{e2}$.

**Table A.3 – System voltages over 72,5 kV –
Typical 2 % switching overvoltages phase-to-earth**

Highest system voltage U_s kV (r.m.s.)	2 % switching overvoltage u_{e2} pu			
	Closing		Three-phase reclosing	
	Without resistors	With resistors	Without resistors	With resistors
>72,5 to 245	2,3	–	3,0	–
300 to 550	2,2	1,8	2,6	2,1
800	–	1,8	–	2,0

**Table A.4 – System voltages over 72,5 kV –
Typical 2 % switching overvoltages phase-to-phase**

Highest system voltage U_s kV (r.m.s.)	2 % switching overvoltage u_{p2} pu			
	Closing		Three-phase reclosing	
	With resistors	Without resistors	Without resistors	With resistors
>72,5 to 245	3,5	–	4,5	–
300 to 550	3,4	2,9	3,9	3,2
800	–	2,9	–	3,2

Annex B (informative)

Dielectric strength of air

The shape of a standard switching impulse used for tests has a 250 μ s time-to-crest and a 2 500 μ s tail. The switching overvoltages arising on operating power systems have a time-to-crest ranging from 50 μ s to 2 000 μ s. The time-to-crest of this overvoltage has a considerable influence on the disruptive withstand voltage U_{50} of an air gap and varies with the air gap distance. The magnitude of the voltage is least at a so-called critical time-to-crest. A wave form with a critical time-to-crest should be assumed in determining the minimum approach distance.

As a result of numerous switching impulse tests, air gaps can be characterized by the minimum strength observed for the critical time-to-crest of the transient overvoltage, as a function of the geometrical characteristics of the air gap, which are mainly the gap spacing and the electrode configuration. Among different gaps of the same spacing, d (in metres), the positively stressed rod-plane gap has the lowest strength and is used as a reference. For practical rod-plane gaps of length up to 25 m, the positive-polarity critical-front-time dielectric strength U_{50RP} is given by (formula 4.5 of CIGRÉ Brochure 72):

$$U_{50RP} = 1\,080 \ln(0,46\,d + 1) \text{ kV} \quad (\text{B.1})$$

For other gap configurations, and to take account of other effects, the statistical withstand voltage U_{90} can be determined by applying a factor K_t as follows:

$$U_{90} = K_t U_{50RP} \quad (\text{B.2})$$

that is:

$$U_{90} = K_t 1\,080 \ln(0,46\,d + 1) \quad (\text{B.3})$$

By transforming equation (B.3) and taking into account the floating object distance F , one obtains equation (8) for the electrical distance D_U .

For each gap distance, and under the same atmospheric conditions, there is a statistical variation in breakdown voltage. The probability of breakdown is usually assumed to have a normal (Gaussian) distribution based on tests. The conventional deviation of this distribution varies with wave form, polarity of the overvoltage, gap geometry and atmospheric conditions.

The relation between the statistical withstand voltage U_{90} and the 50 % disruptive discharge voltage U_{50} is:

$$U_{90} = U_{50} - 0,0128 s_e U_{50} \quad (\text{B.4})$$

where s_e is the normalized value of the conventional deviation of U_{50} expressed in percent. Defining k_s as:

$$k_s = 1 - 0,0128 s_e \quad (\text{B.5})$$

equation (B.4) becomes:

$$U_{90} = k_s U_{50} \quad (\text{B.6})$$

Unless the value of s_e is known from tests representative of the gap configuration and distance concerned, a value of $s_e = 5 \%$ should be assumed. Equation (B.5) then becomes:

$$k_g = 0,936 \quad (\text{B.7})$$

Annex C **(informative)**

Gap factor k_g

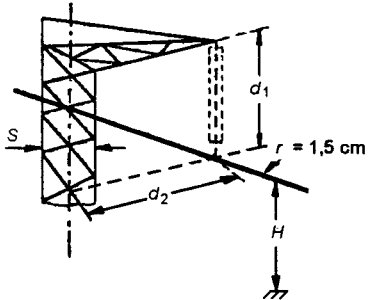
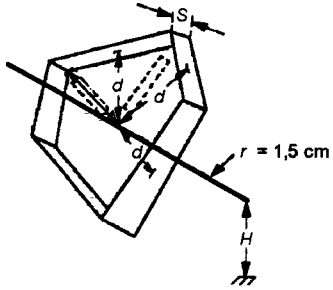
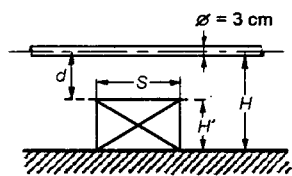
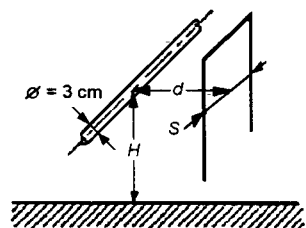
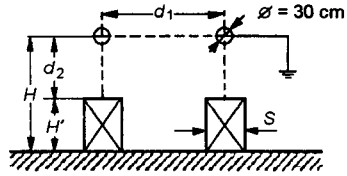
One of the greatest influences on the electrical strength of gaps above 1 m is the shape and size of the energized and the earthed conductive parts. The weakest of the gap configurations is the rod-plane with a positive switching impulse applied to the rod.

If the earthed conductive part is different from a plane and/or the live conductive part is larger than a rod U_{50} is greater than for the rod-plane configuration by a so-called "gap factor" k_g . The smaller the earthed conductive part (e.g., tower, bus support structure) and the further it is from the earth plane, the greater the value of k_g , up to the limit where the configuration becomes an isolated conductor-rod gap, which has the greatest electrical strength.

Typical gap factor values for common configurations are shown in table C.1, reproduced from CIGRÉ 72, and also in IEC 60071-2. Table C.1 also gives expressions for the gap factor k_g (shown here as "k") permitting its calculation for different gap configurations. Refer to CIGRÉ 72 for further details regarding determination of the gap factor.

It is suggested that a gap factor be chosen from the range of values given in table C.1, to calculate the electrical distance. Under certain circumstance, such as a conductor dead-ending on a wide structure and having no grading rings (unlikely for systems above 300 kV), or for work near conductors passing over large structures, the gap factor may be as low as 1,1. Conversely, for narrow structures the gap factor may approach 1,6. The gap factor may be general and may cover several structure types.

Table C.1 – Gap factor for some actual configurations

Configuration	Formula	Typical value
Conductor-cross-arm 	$k = 1,45 + 0,015 \left(\frac{H}{d_1} - 6 \right) + 0,35 (e^{-8 S/d_1} - 0,2)$ $+ 0,135 \left(\frac{d_2}{d_1} - 1,5 \right)$ Applicable in the range: $d_1 = 2 + 10 \text{ m} \quad d_2/d_1 = 1 + 2$ $S/d_1 = 0,1 + 1 \quad H/d_1 = 2 + 10$	$k = 1,45$
Conductor-window 	$k = 1,25 + 0,005 \left(\frac{H}{d} - 6 \right) + 0,25 (e^{-8 S/d} - 0,2)$ Applicable in the range: $d = 2 + 10 \text{ m} \quad S/d = 0,1 + 1 \quad H/d = 2 + 10$	$k = 1,25$
Conductor-lower structure 	$k = 1,15 + 0,81 \left(\frac{H'}{H} \right)^{1,167} + 0,02 \frac{H'}{d}$ $- A \left[1,209 \left(\frac{H'}{H} \right)^{1,167} + 0,03 \left(\frac{H'}{H} \right) \right] (0,67 - e^{-2 S/d})$ where $A = 0$ if $S/d < 0,2$ and $A = 1$ if $S/d > 0,2$ Applicable in the range: $d = 2 + 10 \text{ m} \quad S/d = 0 + \infty \quad H'/H = 0 + 1$	$k = 1,15$ for conductor-plane to 1,5 or more
Conductor-lateral structure 	$k = 1,45 + 0,024 \left(\frac{H'}{H} \right) - 6 + 0,35 (e^{-8 S/d} - 0,2)$ Applicable in the range: $d = 2 + 10 \text{ m} \quad S/d = 0,1 + 1 \quad H/d = 2 + 10$	$k = 1,45$
Rod-rod structure (open switchgear) 	Horizontal rod-rod-structure $k_1 = 1,35 - 0,1 \frac{H'}{H} - \left(\frac{d_1}{H} - 0,5 \right)$ Rod-lower structure $k_2 = 1 + 0,6 \frac{H'}{H} - A 1,093 \frac{H'}{H} (0,549 - e^{-3 S/d_2})$ where $A = 0$ if $S/d_2 < 0,2$ and $A = 1$ if $S/d_2 > 0,2$ Applicable in the range: $(k_1) \quad d_1 = 2 + 10 \text{ m} \quad d_1/H = 0,1 + 0,8 \quad d_1 < d_2$ $(k_2) \quad d_2 = 2 + 10 \text{ m} \quad S/d_2 = 0 + \infty \quad d_2 < d_1$	$k_1 = 1,3$ $k_2 = 1 + 0,6 \frac{H'}{H}$

Annex D (informative)

Allowing for atmospheric conditions

The insulation strength of a given air gap increases with air density and with the humidity of the air up to the point where condensation forms on insulator surfaces. The empirically determined electrical strength of particular gaps, as described by equation (B.1) for instance, is normally applicable at standard atmospheric conditions (20 °C, 101,3 kPa, 11 g/m³ humidity). But, for minimum approach distances to be appropriate for all anticipated atmospheric conditions, the range of influence of these three atmospheric factors on the electrical strength of the air gap shall be known.

The method used here, to allow for adverse atmospheric conditions, is as defined in IEC 60060-1 [4]. Accordingly, the atmospheric correction factor K is given by:

$$K = k_1 k_2$$

where

k_1 is the air density correction factor;

k_2 is the humidity correction factor.

D.1 Air density

The effect of air density is accounted for by the relative air density δ given by:

$$\delta = (p/p_0) [(273 + t_0) / (273 + t)]$$

where

t and p are the actual temperature and barometric pressure;

t_0 and p_0 are the standard temperature and pressure of 20 °C and 101,3 kPa.

Hence:

$$\delta = 2,89 p / (273 + t)$$

The air density correction factor k_1 depends on the gap configuration and type of overvoltage which can be accounted for by an exponent m on the relative air density, i.e.:

$$k_1 = \delta^m$$

The combination of temperature and air pressure giving the lowest air density and hence the lowest gap breakdown voltage is high temperature and low pressure. However, the highest expected temperature and lowest pressure are unlikely to occur simultaneously.

CIGRÉ 72 proposes two more accurate methods of correcting for air density: a physical method, and the following empirical expression which is based on investigations conducted up to 3 000 m and was derived for positive switching impulses to fit data for various air gap configurations:

$$\frac{U}{U_0} = \frac{0,8 [1 + T(1-d)] (d - 0,2 g_0)}{(1 - 0,2 g_0) a} + 0,2 \quad (D.1)$$

where U_0 is the breakdown voltage in standard conditions, in kilovolts.

$$T = 1,4 \frac{1 - 0,8 g_0}{1 - 0,2 g_0} (k_g)^{1,6} \quad (D.2)$$

$$g_0 = \frac{U_0}{500 d \left[1 + \frac{k_g - 1}{3} \right]} \quad (D.3)$$

where d is the air gap length, in metres.

D.2 Humidity

The effect of humidity on the breakdown voltage is complex. It is usually accounted for by a factor defined as k in IEC 60060-1, the value of which is empirically related to humidity, and an exponent w , which depends on the gap length and configuration, and on the waveshape. Thus the humidity correction factor k_2 is:

$$k_2 = k^w$$

The value of w , as well as the exponent m for the relative air density, can be determined by the methods given in IEC 60060-1.

D.3 Altitude

The electrical strength of an air gap is weakened at higher altitude, due to the reduced air pressure, although the reduced temperature and humidity have a modifying effect. The reduction in pressure with altitude can be calculated from the expression:

$$p/p_0 = e^{-(H/8\,150)} \quad (D.4)$$

where H is the height above sea level, in metres.

The mean air pressure at a certain altitude can then be assumed to be the standard pressure (101,3 kPa) corrected for altitude, with variations in pressure occurring around this value.

However, because the average temperature and humidity generally decrease with altitude, the overall atmospheric correction factor k_a should take this into account. The temperature and humidity variations are likely to vary depending on geographical location, and a precise value of the mean correction factor for the altitude of a given location can only be determined by analysis of local weather data. The correction factor determined in this way also depends on the gap length and configuration, and overvoltage wavefront.

To avoid having to apply an altitude correction for every installation in a power system, a common correction factor is usually taken for all installations at elevations up to an appropriate reference altitude, below which most of the power system is located. Other correction factors can then be determined for further ranges of altitude above this reference altitude. A reference altitude of 1 000 m is suggested here since it is commonly used, including in IEC 60038. But some power systems are situated at altitudes well below the 1 000 m elevation; thus table D.1 shows values for lower altitudes so that a higher and less restrictive value of k_a can then be used.

D.4 Total atmospheric correction factor

As low temperature (high air density) is always associated with low humidity, the air density and humidity correction factors partially cancel each other, and the total atmospheric correction factor for any given location varies only little with time. The total correction factor can be described statistically by a mean value k_a and a relatively small normalized conventional deviation of up to about 1,5 %. The mean value is almost entirely determined by the altitude. The normalized conventional deviation s_a of k_a can be combined with the deviation of the air gap breakdown voltage s by:

$$s_t = \sqrt{(s_a^2 + s^2)}$$

Since the s_a of 1,5 % is small compared with the suggested value of s of 5 %, it has only little effect on the total deviation s_t . It should be noted, however, that for altitudes above about 1 000 m, s_a may have values greater than 1,5 %.

The values of k_a given in table D.1 can be derived using equations (D.1) to (D.4), based on standard temperature and humidity (20 °C and 11 g/m³) and using equation (8) with $k_g = 1,2$ to determine the factor g_o . Note that larger gap lengths give larger values of k_a .

It has been found that when k_a is calculated using actual climate data from meteorological stations located at different altitudes (instead of assuming standard values of humidity and temperature of 11 g/m³ and 20 °C), the values of k_a are higher than the value calculated above, so that the calculated values of k_a are probably conservative. More precise, and probably higher, values of k_a can be determined by analysis of actual meteorological data.

**Table D.1 – Atmospheric factor, k_a
for different reference altitudes and values of U_{90}**

Altitude	Range of U_{90} kV						
m	<199	200-399	400-599	600-799	800-999	1 000-1 190	>1 200
0	1,000	1,000	1,000	1,000	1,000	1,000	1,000
100	0,990	0,992	0,993	0,995	0,996	0,998	0,999
300	0,970	0,975	0,980	0,984	0,988	0,992	0,995
500	0,950	0,958	0,966	0,973	0,980	0,985	0,991
1 000	0,901	0,916	0,931	0,944	0,955	0,966	0,976
1 500	0,853	0,875	0,894	0,912	0,928	0,943	0,956
2 000	0,807	0,833	0,857	0,879	0,899	0,917	0,933
2 500	0,763	0,792	0,820	0,845	0,868	0,888	0,908
3 000	0,720	0,752	0,782	0,810	0,835	0,858	0,880

D.5 Correction for altitudes greater than 1 000 m

For live work at altitudes greater than the reference altitude D_U shall be multiplied by an altitude correction factor which can be calculated using the equations (D.1) to (D.4). If a reference altitude of 1 000 m is chosen, the applicable value of the altitude correction factor can be taken from table D.1.

**Table D.2 – Altitude correction factor for altitudes
above a reference altitude of 1 000 m**

Altitude	Electrical distance D_U m						
m	0,5	1,0	1,5	2,0	2,5	3,0	4,0
1 000	1,050	1,045	1,041	1,038	1,035	1,033	1,028
2 000	1,103	1,094	1,087	1,081	1,076	1,071	1,064
2 500	1,161	1,148	1,137	1,129	1,122	1,115	1,105
3 000	1,224	1,206	1,193	1,182	1,173	1,166	1,153

D.6 Method of calculation of values in table D.1

The following steps were used to calculate each of the values given in table D.1:

- a) U_{90} is the lower value in the range (e.g. 200 kV in the 200 kV to 399 kV range);
- b) $U_0 = U_{50} = U_{90} / 0,936$ is the breakdown voltage for standard conditions;
- c) let $k_g = 1,2$;
- d) $d = 2,17 (\exp^{U_{90}/(1080 k_s k_g)} - 1)$ (equation 8), i.e. the gap with $k_g = 1,2$ that would withstand U_{90} at standard atmospheric conditions ($k_s = 0,936$);
- e) calculate g_0 using equation (D.3);
- f) calculate T using equation (D.2);
- g) calculate $\delta (= p/p_0)$ for the altitude using equation (D.4) (this assumes that δ changes only with mean pressure and there is no change in mean temperature with altitude);
- h) calculate $k_a (= U/U_0)$ using equation (D.1).

Annex E **(informative)**

Live working near contaminated, damaged or moist insulation

E.1 Contaminated insulation

When contamination is present, the response of the external insulation to power frequency voltage becomes important and may dictate external insulation design. Flashover of insulation generally occurs when the surface is contaminated and becomes moist due to light rain, snow, ice, dew or fog, if significant washing does not occur.

Live working may be carried out provided that:

- the actual creepage length of the insulators in the work area has been checked, taking into account the design length and possible reduction by damaged insulators, and the system operating voltage;
- the actual conditions of contamination and humidity existing when live working is to be done are checked for deviation from the conditions assumed for design purposes, and it is found that the design allows for this contamination level.

Besides, contamination flashover is a gradual process, preceded by visible scintillation, audible discharges and eventual partial flashover, so that there is prior warning. If these phenomena occur live work should not be carried out.

E.2 Defective cap and pin insulators

A large amount of live working is devoted to the replacement of damaged cap and pin insulator strings. Thus it is important to know the extent of insulation damage up to which it is possible to work on or near the system insulation without risk of flashover. The residual electrical strength of a string of cap and pin insulators that includes damaged units can vary significantly depending upon the type of insulators, the number and location in the string of the damaged units, and their degree of damage.

The general trend of these variations is as follows:

- the dispersion of the strength reduction is significantly larger with porcelain than with glass insulators. This is due to the fact that prestressed toughened glass insulators always shatter completely, leaving a bare hub, while porcelain insulators may be broken in different ways, so that the strength depends very much on the portion of porcelain skirts that remains;
- the worst position of damaged units is generally near the line end. The strength is higher if the same number of damaged units is at the structure end, and still higher if they are in the middle of the string. However, the exact conditions of the maximum reduction in insulation strength depends also on the electric field distribution along the string, that is, on the length of the string, the type of fittings at the line end (e.g. grading rings) and the type of structure.

Obviously, the larger the number of damaged units, the greater the reduction of strength. But, even if all the insulators are damaged, a dry insulator string still maintains 20 % of its strength. The variation of the strength as a function of the number of damaged units can be assumed to be linear as a first approximation, and analysis of a large amount of test data leads to equation (10).

Example of the use of $k_i < 1,0$:

Taking a 220 kV system, with a required withstand voltage for live working (U_{90}) of 565 kV_{peak} and using 14 glass insulator units ($k_d = 1$) per string. Assume $k_a = 0,931$, $k_g = 1,4$; $k_s = 0,936$ and $k_f = 1$, the following values of the minimum required system insulation length D_U can then be calculated using equation (8):

Table E.1

n	n_d/n_o	k_i	D_U
1	0,071	0,943	1,23
2	0,143	0,886	1,35
3	0,214	0,829	1,47
4	0,286	0,771	1,61
5	0,357	0,714	1,79
6	0,429	0,657	2,00
7	0,500	0,600	2,26

For 146 mm long units the string length is about 2,0 m. In order to remove or change insulator strings with more than six damaged units, measures shall be taken to reduce the maximum overvoltage magnitude (e.g. by preventing reclosing or by using protective gaps).

Annex F **(Informative)**

Reduction of distances below the calculated value

F.1 Effect of tools for live working

During live working, the strength of the system insulation can be reduced by the introduction, into the air gap, of tools with metallic fittings or various conducting equipment required for the work in progress. During barehand work, the worker in conductive clothing is transferred, at a given time, from the earthed structure to the live conductor, and vice versa. Furthermore, when the worker is at the conductor the conductor-earth air gap is changed, which may alter the gap factor and the dielectric strength depending on the size and position of the conductive objects introduced into the air gap.

The influence of tools or worker cannot be correctly calculated but should be determined by laboratory tests on representative configurations.

The electrical strength of tools for live working is also reduced by wetting, although this can be combatted, for some tools used for work up to medium voltage only, by the use of weather sheds. Proper coating of the surface is also a valid technique (e.g. the use of silicone coatings). In any case, the surface of all tools shall always be kept clean and in good condition.

F.2 Small conductive pieces

The length of the air gap is reduced by the length (along the gap axis) of conductive pieces introduced into, or already present in, the gap. These pieces can be introduced or present at the live end or the dead end of the insulation, or they can be at a floating potential within the gap. But, whatever the location, the strength of the gap decreases as the number and/or length of the pieces increase. Consequently, it is important that any metallic components be as small and few as possible.

To take into account the presence of these small conductive pieces, it is sufficient, from a practical point of view, to subtract the sum of their maximum dimensions F measured along the gap axis, from the overall length of the air gap D and to determine the resulting breakdown voltage of the air gap using the equation:

$$U_{50} = 1\,080 \ln(0,46 (D - F) + 1) \text{ kV}$$

F.3 Large conductive objects

The presence of a conductive body in the air gap, or of conductive objects of large dimension L compared to the length of the air gap, creates a distortion of the electric field in the gap.

In this case, and depending on the size and shape of the floating object and its position in the gap, the field distortion can lead to either a decrease or an increase in the strength of the gap. The most severe conditions leading to decrease in strength are obtained when:

- the object has protrusions on the side facing the earthed structure;
- the object is on or near the gap axis;
- the distance between the object and the live conductor lies between a quarter and a third of the total air gap length.

In these critical conditions, the strength can be given by the formula:

$$U_{50} = U_{50} (0,6 + 0,02 D - 0,54 L/D) \quad (F.1)$$

U_{50} is the breakdown voltage of the gap without the object;

D is the minimum distance between live and earthed electrodes;

L is the maximum dimension of the object.

As for small conductive pieces, it is easier to compare this strength to one of an air gap having the total length of air equal to $D-L$, or $D-F$, F being the sum of the dimensions L of all the floating electrodes present in the gap.

The minimum strength of the gap in the presence of a floating object can then be predicted by equation (F.2), where k_f is a constant applicable to floating electrodes. Its value lies generally between 0,85 and 1,15, but values down to 0,6 can be reached in some cases.

$$U_{50} = 1\,080\, k_f \ln(0,46 (D + F) + 1) \text{ kV} \quad (F.2)$$

It has been recognized that, at system voltages higher than 72,5 kV, the critical size for large objects is about 0,30 m. At voltages lower than 72,5 kV, the critical size is reduced to 0,15 m if the floating electrode remains in the air gap in a fixed position. The criteria for 0,15 m and 0,3 m for the application of the $k_f < 1$ have been chosen for practical reasons. There is no physical justification for choosing precisely these criteria and only the two values 1 and 0,85 for k_f . In reality, every value of L has some effect, but not always so much as to require a k_f as low as 0,85.

Values suggested for k_f are 0,85 for large electrodes (above the critical size) and 1,0 for small electrodes (below the critical size).

Annex G **(informative)**

Ergonomic distance

Two approaches, or a blend of both, can be used to establish an ergonomic safety margin:

- specify only an absolute smallest minimum approach distance and let the skilled worker decide the extra distance required for the particular job to be done;
- specify a complete minimum approach distance allowing a sufficient safety margin to account for all possible contingencies.

A number of factors shall be considered before specifying the minimum approach distance, or commencing work close to a live conductor. As it is impractical and inappropriate to recommend an ergonomic distance here, the following points are provided as guidelines for consideration by individual organisations.

G.1 Training, knowledge and skill

Basic to live working is knowledge of the hazards and means of personal protection, by minimum approach distances and other methods. Workers shall have been thoroughly trained in live work and in the job at hand before live work at the smallest approach distance is begun. During work, attention shall be shared between the work and observing the minimum approach distance. Adequate training and practice in the work procedure will reduce the possibility of attention being diverted from observing the minimum approach distance by unexpected situations.

G.2 Protective barriers

Barriers placed between the workers and the live conductors may provide the required insulation level, or merely serve as a mechanical barrier. Only fully insulating barriers with adequate mechanical strength can be placed closer to the live conductors than the minimum approach distance.

G.3 Possibility of error

The possibility of errors being committed during the work depends on the work procedure being used, personal factors, effects of the environment and the extent to which the workers' actions are monitored by others.

G.4 Work procedure

Different work positions and methods will require different allowances for unintentional movement, e.g. working beneath a live conductor is less hazardous than working alongside it. The stability of the worker's position can also vary from task to task, e.g. working above the ground, compared with working on the ground. A complex or strenuous job is also more likely to divert the worker's attention away from observing the minimum approach distance.

Because of these factors, consideration could be given to using a different minimum approach distance for different work situations or procedures.

Strict adherence to safe work procedures is emphasized when work is undertaken at the smallest minimum approach distance.

G.5 Personal factors

A worker's physical, mental and emotional states are also possible causes for unintentional movement. These factors are, in turn, influenced by the duration and strenuousness of the job, for instance. Live working requires constant attention, both to the procedures and the minimum approach distance, attention which can be readily distracted by personal factors. A worker who is in any way impaired should not be permitted to work at the smallest minimum approach distance.

A worker's ability to judge the minimum approach distance correctly is also important. For this reason it may be beneficial to increase the ergonomic distance with the voltage. However, too large a distance at high voltages will make small components on the live conductors difficult to see, and tools heavier to handle.

Workers shall not wear clothing with loose parts that could fall, blow or swing close to the live conductors.

G.6 Environmental factors

Certain environmental influences are generally taken into account by prohibiting work at the minimum approach distance under those conditions. For instance, work is normally not permitted during nearby thunderstorms, in heavy rain or when there is a continuous film of moisture on the surface of insulating tools.

Adverse conditions may also be created by other environmental conditions, either directly, or by diverting attention away from observing the minimum approach distance. Strong winds move conductors, supports or equipment (e.g. aerial devices) dangerously. Dust storms are an eye hazard. Ice on structures will make footing insecure. Woodpecker holes present a climbing hazard. Mist or sea spray may pose a hazard to system or tool insulation. Smooth surfaces may be slippery. Darkness or glare may impair vision.

These are some of the environmental influences on work close to live conductors, some of which will need to be taken into account when establishing minimum approach distances.

G.7 Monitoring

To warn workers of dangerous situations arising during the work, it can be very beneficial to require continuous monitoring by an observer, located at some distance from the work. Failing that, the workers should be encouraged to describe aloud to one another each step in the work procedure before taking it. The procedure to be followed should also be detailed and discussed between the foreman and workers before commencing work.

Annex H
(informative)

Bibliography

- [1] CIGRÉ, Brochure No. 72: Guidelines for the evaluation of the dielectric strength of the external insulation
- [2] CEI 60071-2:1996, *Insulation co-ordination – Part 2: Application guide*
- [3] CEI 60038:1983, *IEC standard voltages*
- [4] CEI 60060-1:1989, *High-voltage test techniques – Part 1: General definitions and test requirements*

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